Economics of Controlled Drainage and Subirrigation Systems

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Introduction

To reduce water-related stress on their crops, many farmers in North Carolina's lower coastal plain are considering the installation of a dual-purpose system of underground tubing that can be used for both subsurface drainage and subirrigation.

During periods of excessive rainfall, the system provides **subsurface drainage** to remove excess water from the field. During dry periods when soil moisture is low, the drainage outlet can be managed to limit the amount of water discharged, thus providing **controlled drainage**, or the system can be used for **subirrigation** by adding water above (upstream from) the outlet.

The design, operation, and management of such a system is discussed in Extension publication AG-355,*Agricultural Water Management for Coastal Plain Soils*, and AG-356, *Operating Controlled Drainage and Subirrigation Systems*.

On poorly drained soils these systems can be very cost effective when compared to the combination of a conventional drainage system and an overhead sprinkler irrigation system. However, their cost effectiveness varies considerably from one location to another and depends on the crop, soil, topography, climate, water supply, and degree of management.

Before installing a dual-purpose subsurface drainage and subirrigation system on your farm, have your site evaluated by the local Soil Conservation Service (SCS) to determine whether this option is suitable for your farm and your needs. If your site is found to be physically suitable, this publication will help you determine whether installing this type of system will be a wise investment. (In the following discussion the term *drainage and subirrigation system* is used to refer to a combination subsurface drainage and subirrigation system.)

System Costs

The three major expenses of installing and operating a drainage and subirrigation system are the costs of providing a water supply, installing the underground tubing, and performing the necessary land grading. Also to be considered are the costs of control structures, culverts, drop inlet pipes, field borders, and annual operating and maintenance expenses. Because these costs vary from one installation to another, the information presented here should be used only as a general guide. Actual costs may be as much as two or three times higher or lower, depending on the conditions on your farm and the management strategy you use.

A controlled drainage system without subirrigation does not require a water supply, but such a system provides considerably less protection against drought.

Water Supply Costs

The cost per acre of installing a subirrigation system depends heavily on the cost of providing a water supply. Because the costs associated with the different sources vary widely, the source and cost of the water supply should be considered carefully during the planning stages.

The water sources commonly used in the coastal plain are ponds (usually formed by excavating), rivers and streams, and deep wells. Excavated ponds are usually not very well suited for irrigating large acreages because they must be very large in order to store enough water to last through the irrigation season. For example, to store enough water to irrigate 100 acres during a normal season would require at least a 7-acre pond 10 feet deep, which would cost $50,000 to $60,000. In some instances, however, the pond may penetrate a shallow, water- bearing sand layer that can recharge the water supply within a few hours or days. Another alternative is to recharge the pond with small wells that penetrate a surficial aquifer. A much smaller pond can be used if it can be recharged. Recharging a pond with deep groundwater is also feasible.

The water supply cost may be only a few dollars per acre if a supply of surface water such as a stream or river is nearby and if water can be diverted to flow from this source to the subirrigation system by gravity. Even if the water must be pumped to the subirrigation site, a stream or river is still a relatively in- expensive source. A major canal draining a large, undeveloped, forested area can provide an inexpensive (but limited) supply of water. Unfortunately, this type of source will often dry up during extreme droughts and will therefore be unreliable during the period of most critical need.

At the opposite extreme in terms of cost are deep wells, which are the most reliable source of water but may add several hundred dollars per acre to the cost of a system. In certain areas-for example, in some of the northeastern counties-even a deep well may be unreliable or prohibitively expensive because of salinity problems and excessive pumping requirements.

Deep well costs vary according to the well's location, type, casing size, depth, and required yield. Other factors affecting costs are the availability of well drillers and whether a guarantee is required. For assistance in choosing a well location and developing yield and cost estimates, contact local well drillers who have experience in drilling irrigation wells in your area and talk to the groundwater hydrologists from the North Carolina Department of Natural Resources and Community Development.

Drilling a test well is one way to obtain a more reliable estimate of total well cost and yield for your location. If other wells have been drilled nearby, however, a test well may not be needed. Requiring the well driller to guarantee that the well will deliver a specified amount of water is not recommended because doing so can increase the cost substantially.

Easy access to the site will normally reduce the well cost, as will scheduling the drilling for a time when the driller is in the area rather than requiring that a special trip be made. Gravel-packed wells and wells requiring screens will cost more than open-end wells.

Agricultural Extension Service publication AG-389, *Water Supplies for Subirrigation*, discusses water supplies in more detail.

Underground Tubing Costs

The cost of buying and installing perforated corrugated plastic tubing will depend on the total footage to be installed, the tubing diameter, the method of installation, and the type of filter material (if any) to be used. Normally, the cost of tubing and installation will be the largest single expense for either a controlled drainage or a subirrigation system.

The amount of tubing required depends largely of the hydraulic conductivity of the soil-the ease with which water moves through the soil. At some sites in North Carolina the hydraulic conductivity is high enough that underground tubing (in addition to existing field ditches) will not be needed for either drainage or subirrigation. In this case, the cost of a controlled drainage or subirrigation system will be small. However, such situations are the exception. Most soils and sites in North Carolina require the placing of tubing at a spacing from 40 to 100 feet to provide the necessary internal water movement. Some soils are so "tight" that spacings of less than 40 feet are required. In these situations the cost of the tubing alone will usually make the system too expensive tobe practical.

Four-inch-diameter tubing will usually provide adequate capacity for controlled drainage or subirrigation. This size is somewhat smaller than that normally used for drainage alone because the tubing is placed 30 to 50 percent closer in a controlled drainage or subirrigation system. The cost of 4-inch tubing varies from about 17 to 23 cents per foot, depending on the quantity of tubing purchased and the location of the system. Tubing cost increases significantly as the diameter increases, and it normally decreases slightly as the total number of feet purchased increases. Filter material, if needed to stabilize subsoils with a fine sandy or silty texture, will add 7 to 12 cents per foot, depending on the type of fabric used. Six types of fabric are now approved by the Soil Conservation Service for use in North Carolina. Contact your local SCS representative for more specific information and recommendations for your local area.

Installation costs are quite variable. They depend on the size of the job, the distance from the contractor's place of business, and the method of installation. For example, installation costs for 4-inch tubing range from about 30 cents per foot for large jobs (more than 25,000 feet) to more than 50 cents per foot for small jobs. Installation costs increase slightly as the tubing diameter increases and are somewhat higher if a filter material is used. The cost is normally lower when the tubing is installed with the "plow" type machine rather than the "trencher" type, mainly because the operation is much faster with the plow machine. It is somewhat more difficult, however, to check that the proper grade has been established when the plow machine is used. Also, recently cleared or root-infested fields may make installation with the plow machine more diffficult. Machines with laser equipment usually do a better job of maintaining the proper grade. Regardless of equipment used, tubing installation should be scheduled when the soil is dry to minimize smearing of the trench walls.

Tubing costs per acre based on average prices for several spacings and tubing diameters are shown in Table 1.

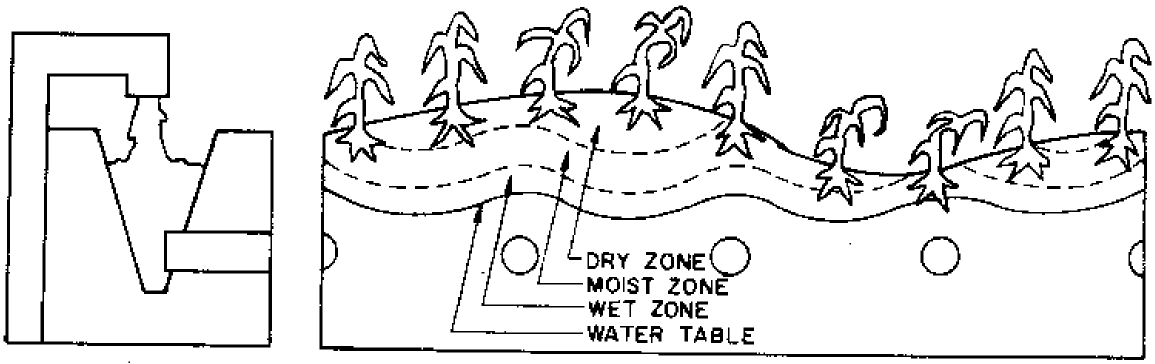

Figure 1a. Uneven moisture distribution that occurs with subirrigation when the surface is uneven. Ideally, most roots should be in the moist zone. When most of the roots are in the wet zone, the plants tend to drown; when most of the roots are in the dry zone, the plants suffer from drought.

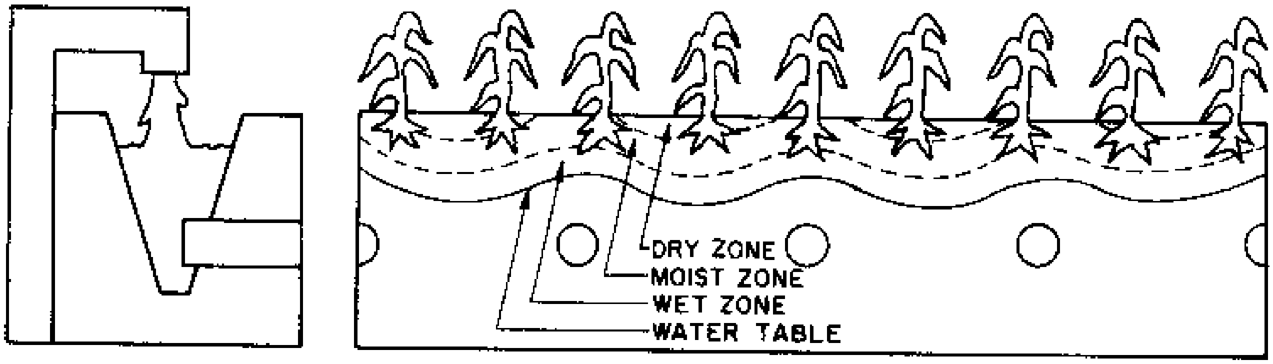

Figure 1b. Uniform moisture distribution that occurs with subirrigation when the field is graded flat. Most of the roots are in the moist zone even though the water table undulates above the tile lines.

Table 1. Installed Cost of Drain Tubing as a Function of Spacing and Size

		Tubing diameter					
		4 inches		5 inches		6 inches	
Drain spacing (feet)	Length per acre (feet)	Initial cost ($/acre)	Increased return* needed to break even ($/acre/year)	Initial cost ($/acre)	Increased return* needed to break even ($/acre/year)	Initial cost ($/acre)	Increased return* needed to break even ($/acre/year)
33	1,320	$792.00	$98.32	$990.00	$122.90	$1,214.40	$150.76
50	871	522.72	64.89	653.40	81.11	801.50	99.50
60	726	435.60	54.08	544.50	67.59	667.92	82.92
75	581	348.48	43.26	435.60	54.08	534.33	66.33
100	436	261.36	32.44	326.70	40.56	406.75	49.75
150	290	174.24	21.63	217.80	27.04	267.17	33.17
200	218	130.68	16.22	163.35	20.28	200.38	24.87
300	145	87.12	10.82	108.90	13.52	133.58	16.58

Note: Tubing costs were computed by averaging quotes from four contractors and manufacturers. The average cost of 4-inch-diameter tubing is 60 cents per foot; 5-inch tubing is 75 cents per foot; and 6-inch tubing is 91 cents per foot.

* The increased return needed to break even is based on amortizing the initial cost over 30 years at 12 percent interest.

Land Grading Costs

The expense of land grading may be significant for a controlled drainage or subirrigation system. Land grading may be necessary for several reasons.

First, the objective of a controlled drainage or subirrigation system is to maintain the water table throughout the field at a nearly uniform depth below the soil surface. If the land is uneven, the water table may be within the root zone in some areas of the field, while in other areas the water table may be so deep that the plants will suffer from drought stress (Figure 1). The result would be nonuniform moisture distribution. Ideally, the land surface should not vary more than 1/2 foot within the area served by one control structure.

Second, an uneven surface means that the field contains potholes or areas where surface water tends to collect, resulting in drainage problems during wet periods. Land grading eliminates these problem areas and improves surface drainage capacity, thus lowering the cost of the underground tubing. The cost and benefits of land grading should therefore be weighed against the cost of increasing the capacity of the subsurface drainage system.

The cost of land grading will depend on the amount of soil that must be moved to smooth the field and on the distance that it must be transported. If only small potholes are to be filled using soil from nearby areas, the cost may be less than $50 per acre. On the other hand, if a uniform grade is to be established across the entire field to ensure excellent surface drainage and if 1/2 to 1 foot of cut or fill is required in a given area using precision land grading equipment, the cost may exceed $250 per acre.

If the soil characteristics are such that a subsurface drainage system could be effective, installing the system and doing minimal land grading (smoothing the field without regrading it) will normally be more cost effective than extensive regrading to improve surface drainage.

Control Structure Costs

Several types of control structures can be used for controlled drainage and subirrigation systems. The most common is the flashboard riser. These structures may be prefabricated from aluminum, galvanized steel, or asphalt-coated steel. Some farmers have built flashboard risers on the farm or at a nearby machine shop from steel, treated wood, old fuel tanks, or even concrete blocks and concrete. Flashboard risers must be adjusted manually and thus present an increased risk of wet stress during periods of high rainfall when used on systems with limited drainage capacity. Automatic structures are available but have not been used extensively because of their high cost. Head tank control structures are often used when subsurface drain tubing is used for a main instead of an open ditch.

The type of structure, its size, and the method of fabrication and installation will greatly affect the cost. Some small, homemade structures (with a weir less than 24 inches wide) have been fabricated and installed for as little as $300, whereas a large, prefabricated structure (with a weir more than 6 feet wide) may have an installed cost of more than $3,000. Regardless of the type of materials used to make the structure, it should allow the water level to be adjusted easily. It should also be large enough and operated in such a way that the outlet ditch can carry full capacity during critical drainage periods. The size of the structure should meet SCS specifications.

Field Border Costs

All open waterways, such as open ditches, should be stabilized by a grassed border to reduce ditch bank erosion and impede the movement of sediment and nutrients from the field. The land surface should be elevated near the ditch to prevent surface water from flowing into the ditch uncontrolled. The cost of preparing field borders will depend on the size of the border and to some extent on the type of grass used. Field borders can range in width from 3 to 20 feet, depending on the surface drainage pattern and row direction, and they may consume from 1 to 5 percent of the field's total area. A good way to estimate the field border cost is to assume that approximately 2 percent of the total field area will have to be vegetated at an average cost of $1,500 per acre treated. By this method, the total cost would amount to about $30 per production acre.

Miscellaneous Costs

The ditches should be designed so that surface water will enter them only at areas controlled by down spouts or drop inlet pipes. This will reduce ditch bank erosion and ditch maintenance. The number and size of entrance channels required will depend on the smoothness of the field, its surface drainage capacity, and the number of "hoe drains" used to move surface water across the rows. Where good subsurface drainage is provided, the cost per acre of drop inlet pipes is usually very small compared to the total system cost.

If tile outlets drain into the ditch, the system is referred to as an open system, and the tile outlets should be stabilized. Two steps are normally required. First, the ditch bank above the tile outlet should be elevated so that no surface water can enter the ditch near the tile outlet. Second, the ditch bank area that was disturbed by installing the tile should be re-seeded. For some time after the tile has been installed, the disturbed ditch bank is unstable, and surface water running over the bank could undermine the tile outlet. Normally these costs are not included in the contractor's estimate for tubing installation.

If drain tubes rather than open ditches are used for mains, the system is referred to as a closed system. In this type of system, several lateral lines empty into a main line in a manifold arrangement. The main line then empties into an open ditch or at the main outlet.

The advantage of a closed system is that fewer outlets are required, and thus the costs for stabilizing the area near the outlets is reduced. The disadvantage is that failure of one lateral could cause a problem for all laterals on the main.

Since the individual costs for installing and stabilizing outlets are small, it is reasonable to estimate that they will total 5 to 10 percent of the tubing costs for the system.

Economic Evaluation: An Example

To compare the potential costs and benefits of a controlled drainage and subirrigation system with those of other water management strategies, you will need to estimate the costs of installing and operating such a system on your farm. The following example will illustrate the process.

For this example, we will assume that the site is located in a county in eastern North Carolina. The site has been farmed for several years but does not have good natural drainage. A drainage system consisting of a main outlet ditch with lateral ditches at intervals of 300 feet was installed when the site was first prepared for field crops. In its present condition, however, the drainage system (which provides mostly surface drainage) is inadequate and is the primary factor that limits yields. In fact, the land contains several small low areas (amounting to about 5 percent of the total cultivated area) where water accumulates and nearly drowns the crop in many years. Yields are also reduced by drought stress in some years.

For purposes of comparison, the costs of the principal components of drainage and irrigation systems are summarized in Table 2. These values are averages determined from manufacturers' literature, discussions with sales representatives, or actual costs paid by farmers who have installed systems recently. Although these values are typical for the conditions assumed in this example, they are given only to illustrate the method for determining costs. To calculate costs and benefits for your farm, obtain and use figures suited to your situation and local area.

The individual components necessary to make up a complete system depend on the option being considered. An example calculation is discussed below for each component. The total annual cost consists of two types of costs: fixed and variable. Fixed costs include depreciation, interest, property taxes, and insurance. Insurance is recommended only for components that are subject to damage or theft. Since most components of a subsurface drainage and subirrigation system are underground, it is probably unnecessary to insure them, and therefore insurance costs were not included in this example. Also, because property taxes vary from county to county and are generally small compared to other costs, they were not included. If the tax rate is known for a given location, however, property taxes could be included.

Table 2. Description and Estimated Costs of the Principal Components of Water Management Systems

Component	Description and specifications	Initial cost
Drainage Tubing	Four-inch-diameter corrugated plastic pipe with filter (installed).	$.60/foot
Water Supply		
Deep well	8-inch, gravel-packed, 300 feet deep, 80-foot vertical lift, 700 gal/min (at $50/foot).	$15,000
Subirrigation pump and power unit	25-horsepower vertical, hollow-shaft and electric motor with single-stage deep well turbine (230 V, 3-phase power supply, 3,450 rpm, 75% pump efficiency).	$7,000
Center pivot pump and power unit	50-horsepower vertical, hollow-shaft electric motor with 3-stage deep well turbine (230 V, 3-phase power supply, 3,450 rpm, 82% pump efficiency).	$12,750
Surface water supply	River, stream, creek, or large drainage canal.	......
Subirrigation pump and power unit	8-horsepower air-cooled engine drive, type A single-stage centrifugal pump rated at 700 gal/min at 40 feet total dynamic head.	$3,500
Center pivot pump and power unit	40-horsepower air-cooled engine drive, type A single-stage centrifugal pump rated at 700 gal/min at 124 feet total dynamic head.	$8,500
Control Structure	Average value for aluminum or galvanized steel: 6-foot riser, 36-inch weir, 24-inch outlet, 30-foot outlet pipe (installed).	$1,650
Center Pivot	Low-pressure (30 psi) 1,200 feet long with 6 5/8-inch diameter galvanized pipe (at $30/foot).	$36,000

Fixed Costs

Depreciation and interest costs can be determined together by using an amortizing factor for the specific situation. The amortization factor for a particular component takes into account the expected life of the component and the interest rate. Once these are known, the factor can be determined from amortization tables. In this example, the annual interest rate was assumed to be 12 percent and a design life of 15, 20, or 30 years was used, depending on the component. Amortization factors were 0.14682 for 15 years; 0.13388 for 20 years; and 0.12414 for 30 years.

Most economic textbooks contain tables of amortization factors for a wide range of interest rates and design lives. Your local banker, financial planner, or accountant could also provide these values. The amortized cost that must be recovered annually is then determined as follows:

Annual Amortized Cost = Initial Cost x Amortization Factor

Variable Costs

Variable costs are those that depend on how much the equipment is used. They include the cost of repairs and maintenance, fuel, and labor. It is customary to estimate repair and maintenance costs as a fixed percentage of the initial investment for such components as tubing, pumps, and motors; as a fixed rate or percentage for each hour of use for such components as internal combustion engines; or as a fixed rate per year, as in the case of a land-graded surface drainage system. Fuel and labor costs should be estimated on the basis of anticipated usage. The criteria used to determine the variable costs for the example are summarized in Table 3.

Drainage tubing costs are determined by first calculating the length of tubing required for a given spacing. For a spacing of 60 feet:

Length per acre

= area/spacing
= 43,560 square feet per acre/60 feet
= 726 feet per acre

At 60 cents per foot, 726 feet of tubing will require an initial investment of $435.60 per acre. Tubing cost can be amortized over a 30-year period. Thus:

Annual amortized cost = $435.60/acre x 0.12414 = **$54.08/acre/year**

The initial cost and the annual amortized cost (expressed as the increased return needed to break even) for several drain spacings are shown in Table 1.

The operating costs (repair and maintenance costs) for drain tubing were estimated as 2 percent of the annual amortized cost. Thus for the 60-foot spacing:

Annual operating cost = 0.02 x $54.08 = **$1.08/acre/year**

Control structure costs. The surface elevations in the example field vary by 2.5 feet. To provide adequate water table control, it is assumed that three control structures would be needed. To find the total cost:

$1,650/structure x 3 structures =$4,950 initial investment

The expected life of a control structure is about 20 years. Thus:

Annual amortized cost = $4,950 x 0.13388 = $662.71/year

This value represents the control structure cost for the entire 100-acre field. The annual cost per acre would be:

$662.71/100 acres = **$6.63/acre**

Operating costs (repair and maintenance costs) for the control structures can also be estimated as 2 percent of the annual amortized cost.

Annual operating cost = 0.02 x $6.63/acre = **$0.13/acre/year**

Since the operating cost for the control structure is so small, it is neglected throughout the remainder of the calculations. This will normally be the case for large, flat fields. When fields are small, however, repair and maintenance costs for the control structure should be considered.

Table 3. Variable Costs Associated with Water Management Systems

Component	Description, specifications, and bases for cost calculations	Cost
Repair and Maintenance		
Drainage tubing and control structure	Fixed percentage of initial cost.	2% per year
Water Supply		
1. Well	None assumed.	---
2. Pumps and power units	Fixed percentage of initial cost.	1% per year
Center pivot	Fixed percentage of initial cost.	1% per year
Land grading*	Fixed percentage of initial cost.	6.4% per year
Fuel		
Subirrigation system		
1. Well	21.0 brake horsepower required assuming 75% turbine efficiency, 90% motor efficiency at 7 cents/kw-hour.	$1.47 per hour
2. Surface source	6.2 brake horsepower required at 20 feet total dynamic head, 80% pump efficiency, 75% engine efficiency, 11 hp-hour/gal gasoline at $1.10/gal, oil and filters at 15% of fuel.	$0.71 per hour
Center pivot system		
1. Well	44.6 brake horsepower required assuming 80% turbine efficiency, 90% motor efficiency, at 7 cents/kw-hour	$3.12 per hour
2. Surface source	37.6 brake horsepower required at 15 feet total dynamic head, 70% pump efficiency, 75% engine efficiency, 15.5 hp-hour/gal of diesel fuel at $1.10/gal.	$2.67 per hour
3. Self-propulsion drive unit	Six towers with 1-horsepower motor each, half of motors operating at any given time, thus totalling 3 horsepower, 85% efficiency at 7 cents/kw-hour.	$0.25 per hour
Labor		
Subirrigation system	Based on 1/2 hour/day from May 1 to July 31 to check water level in observation wells, adjust riser level, etc. at $5.00/hour, 100 acres.	$2.30 per acre
Center pivot system	Based on 3 minutes/acre-inch, 7 acre-inches/year at $5.00/hour, 100 acres.	$1.75 per acre

*Based on farmers' estimates of $8 per acre per year where the initial cost was $125 per acre.

Water supply costs. For the purposes of this example it is assumed that a deep well will be used as a water source. The expected life of a deep well is about 30 years, and the life of the pump and electric power unit is about 20 years. Thus:

Annual amortized cost of well = $15,000 x 0.12414 = $1,862.10/year

Annual amortized cost of pump and power unit

= $7,000 x 0.13388
= $ 937.16/year

Total annual amortized cost of water supply

= $1,862.10 + $937.16
= $2,799.26/year

Again, this is the cost for the entire 100 acres. The annual cost per acre is: $2,799.26/100 acres = **$27.99/acre/year**

Normally there are no operating costs associated with the water source itself. The costs of repairs and maintenance and of fuel are considered, however, for the pump and power unit. Table 3 indicates that the repair and maintenance cost for the pump and power unit can be estimated as 1 percent of the initial cost. Thus:

Repair and maintenance costs

= $7,000 x 0.01
= $70/year

Since this is the cost for the entire 100 acres, the annual cost per acre is:

$70/100 = $0.70/acre/year

Fuel costs depend on the amount of water that must be applied, the amount of friction loss in the system, and the system operating pressure. For eastern North Carolina, average irrigation volumes range from 6 to 8 acre-inches per year. A value of 7 acre-inches per year was used in this example. The subirrigation process is only about 75 percent efficient because some of the water is lost through seepage to nonirrigated areas. Thus the total amount of water that must be pumped to provide 7 acre-inches of usable water is:

7 acre-inches/0.75 = 9.33 acre-inches/year

To pump 9.33 acre-inches on 100 acres with a pump having a capacity of 700 gallons per minute requires that the pump operate 603.4 hours per year. The power required to pump the water can be determined as follows:

Horsepower required =

[flow rate (gal/min) x total dynamic head (feet)]/
[3,960 x pump efficiency x motor efficiency]

We will assume that the subirrigation water must be lifted 80 feet in the well and is discharged into an open ditch with no discharge pressure. For a pump efficiency of 75 percent and an electric motor efficiency of 90 percent:

Horsepower required

= [700 gal/min x 80 feet]/[3,960 x 0.75 x 0.90]
= 21.0

The energy cost required to provide this power is then:

21.0 horsepower x 1 kw/hp x $0.07/kw-hour = $ 1.47/hour

It was determined the pump must operate 603.4 hours to provide the irrigation water for the entire 100 acres. Thus the annual pumping cost per acre is:

$1.47/hour x 603.4 hours/100 acres = **$8.85/acre/year**

Land Grading Costs. Two levels of land grading were considered in this example. For the first level it is assumed that only the potholes are eliminated using the farmer's land plane at an estimated cost of $75.00 per acre. This method would provide poor to fair surface drainage. For the second case, a laser-controlled land plane is used to produce a completely flat field (one with no grade in any direction) at an estimated cost of $125.00 per acre. This approach would provide fair to good surface drainage. Land grading costs are normally amortized over 20 years. Thus:

Annual amortized cost

= $75/acre x 0.13388
= **$10.04/acre/year**

Maintenance Costs. Operating costs for surface drainage systems generally include the expense of performing routine maintenance of the outlet ditches (mowing and cleanout), constructing hoe drains, and periodically smoothing the field as it becomes uneven as a result of tillage. For an extensive surface drainage system (one that provides good surface drainage), the maintenance cost will average about $8.00 per acre per year. This maintenance cost is very closely correlated to the quality of the surface drainage provided. As the cost of establishing the surface drainage increases, the cost of maintaining the same quality of surface drainage will also be likely to increase.

For the purpose of comparing alternative reasonable to assume that the maintenance cost for a surface drainage system costing $125 per acre will be about $8.00 per acre per year. This value can be adjusted linearly as the initial cost of the system varies from $125 per acre. Therefore, the operating cost for a system providing fair surface drainage (at an initial cost of $75 per acre) can be assumed to be **$4.80 per acre per year**.

Labor Costs. Unlike conventional drainage systems, which by design do not require management, a controlled drainage or subirrigation system should be given daily attention during the growing season. The necessary activities include removing flashboards from the control structure during wet periods, replacing these boards after sufficient drainage has occurred, and monitoring the water table level in the field. The management and operation of these systems is discussed in detail in Agricultural Extension Service publication AG-356, *Operating Controlled Drainage and Subirrigation Systems*. The amount of time and effort required to manage the system varies during the growing season in response to weather conditions, the type of crop, its stage of development, and the system capacity. For this example, it was assumed that the time required for daily management would average 1/2 hour, as indicated in Table 3.

Total system cost includes fixed costs plus variable costs. Taking the subirrigation system with fair surface drainage, a drain spacing of 60 feet, and a deep well water source as an example, the total annual system cost can be computed as follows:

Fixed costs:

- Tubing at 60 cents per foot.....$54.08
- Land grading (fair)................... 10.04
- Control structure 6.63
- Water supply (well)................. 27.99
- Total annual fixed costs $98.74

Variable costs:

- Repairs and maintenance
  - Tubing ....$ 1.08
  - Land grading 4.80
  - Control structure .....neglected
  - Water supply 0.70
- Fuel (electric motor & pump) ... 8.85
- Labor 2.30
- Total variable costs..................$17.73

Total annual system cost per acre $116.47

Selecting the Best Alternative

Knowing the cost of a drainage or irrigation system provides only part of the picture. To determine whether installing a system is a wise investment, the potential benefits in terms of increased yield must also be known. Because a large number of factors are involved and because the calculations can become complex, a computer-based water management model entitled DRAINMOD has been developed to help in comparing alternative systems. This section presents the results obtained when the model was used to compare five different water management options for an example farm. The predicted net return for each of the options is compared to that for the present situation-poor quality surface drainage with a ditch spacing of 300 feet.

Table 4. Summary of Input Soil and Crop Information for DRAINMOD Water Management Model

Soil Properties	
Depth to restricting layer	6.5 feet
Saturated hydraulic conductivity (K)	1.14 inches/hour for depths less than 5 feet; 0.40 inches/hour for depths from 5 to 6.5 feet
Plant-available water content at wilting point	0.09 inch/inch
Saturated water content in root zone	0.37 inch/inch
Required drainage volume for field work	1.5 inches
Minimum daily rainfall to stop field work	0.5 inch
Time after rain before work can resume	2 days
Drainage System Parameters	
Drain depth	3 feet
Drain diameter	4 inches
Surface depressional storage	
Poor to fair surface drainage	1 inch
Fair to good surface drainage	0.4 inch
Drain spacings	33, 50, 60, 75, 100, 150, 200, and 300 feet
Crop Parameters	
Crop	Continuous corn
Desired planting date	Not later than April 15
Working time for seedbed preparation	8 days
Length of growing season	120 days
Maximum effective rooting depth	12 inches

To provide input data for the model, it was necessary to use some representative weather and soil data and make certain other assumptions. Weather data from Wilson, North Carolina, and soil data for a Rains sandy loam were used. It was assumed that the land was continuously planted to corn, and certain other assumptions were made as well. Some of the most important input data are summarized in Table 4. Based on these data and assumptions, the model was used to design the "optimum" system and predict the relative yield responses for each alternative.

Each system component cost was determined using the procedure described in the previous section. Production costs (costs for items such as seed, fertilizer, chemicals, and equipment) were taken from corn production budgets prepared by an Extension economist and adjusted for target yields(Table 5). The price of corn was assumed to be $3.00 per bushel, and the maximum potential yield for the site was assumed to be 175 bushels per acre. If no improvements were made on this site, the average long-term corn yield would be about 80 bushels per acre.

Table 5. Estimated Production Cost for Corn (Coastal Plain— Nonbillbug Areas)

Cost Item	Cost per acre: Nonirrigated (Target yield of 130 bu/acre)	Cost per acre: Irrigated (Target yield of 160 bu/acre)
Variable Costs		
Lime	$10.32	$10.32
Seed	24.75	24.75
Fertilizer, custom applied	26.96	26.96
Nitrogen, custom applied	39.96	49.66
Preemergence Herbicide	14.85	14.85
Insecticide and nematicide	9.70	9.70
Tractor fuel and lubricants	5.00	5.22
Tractor repair	2.29	2.38
Machinery fuel and lubricants	4.61	4.61
Machinery repair	7.74	8.50
Labor	10.09	10.38
Interest on operating capital	7.54	9.26
Total variable costs	$163.81	$176.59
Fixed Costs		
Tractor and machinery ownership (depreciation, taxes, insurance)	$23.68	$24.98
Tractor and machinery interest	21.96	23.16
Total fixed costs	$45.64	$48.14
Total production cost*	$209.45	$224.73

Source: Materials prepared by J. R. Anderson, Jr., Crop Science Extension Specialist, and D. F. Neuman, Extension Economist. North Carolina State University, January, 1985. These costs do not include the costs of the irrigation system, which are considered under system costs in Tables 8 and 9.

*Total production cost does not include charges for use of the land.

Average yields for corn as predicted by the yield version of DRAINMOD using weather data for a 30-year period are given in Tables 6 through 9. Table 6 presents the results for conventional subsurface drainage, Table 7 for controlled subsurface drainage, Table 8 for combined subsurface drainage and subirrigation, and Table 9 for conventional center-pivot overhead sprinkler irrigation with conventional subsurface drainage. These predicted yields were used to estimate the gross income for each alternative. Itemized costs and net return or profit are also shown. Annual net return was calculated by subtracting the estimated annual costs from the predicted annual income. The results for each of the systems are analyzed in the following paragraphs.

Table 6. Predicted Net Return for Conventional Subsurface Drainage on a Poorly Drained Soil Planted to Continuous Corn

	Tile spacing (feet)	Predicted yield (bu/acre)	Gross income per acre	System cost per acre	Production cost per acre	Total cost per acre	Net return per acre
Fair surface drainage	33	135.1	$405.30	$115.19	$209.45	$324.64	$80.66
	50	135.6	406.88	81.08	209.45	290.53	116.35
	60	135.4	406.35	70.06	209.45	279.51	126.84
	75	134.6	403.73	59.03	209.45	268.48	135.25
	100	134.0	390.08	47.98	209.45	257.43	132.65
	150	105.9	317.63	36.96	209.45	246.41	71.22
	200	91.7	275.10	31.44	209.45	240.89	34.21
	300	81.2	240.00	20.51	209.45	229.96	10.04
Good surface drainage	33	135.1	405.30	125.03	209.45	334.48	70.82
	50	135.8	407.40	90.92	209.45	300.37	107.03
	60	135.8	407.40	79.90	209.45	289.35	118.05
	75	135.6	406.88	68.87	209.45	278.32	128.56
	100	131.8	395.33	57.82	209.45	267.27	128.06
	150	112.4	337.05	46.80	209.45	256.25	80.80
	200	102.0	306.08	41.28	209.45	250.73	55.35
	300	92.9	$278.78	$29.95	$209.45	$239.40	$39.38

*Net return is return or profit to land and management based on a corn price of $3 per bushel.

Table 7. Predicted Net Return for Controlled Subsurface Drainage on a Poorly Drained Soil Planted to Continuous Corn

	Tile spacing (feet)	Predicted yield (bu/acre)	Gross income per acre	System cost per acre	Production cost per acre	Total cost per acre	Net return per acre
Fair surface drainage	33	141.6	$424.73	$121.82	$209.45	$331.27	$93.46
	50	139.5	418.43	87.71	209.45	297.16	121.27
	60	138.3	414.75	76.69	209.45	286.14	128.61
	75	135.5	406.35	65.66	209.45	275.11	131.24
	100	127.6	382.73	54.61	209.45	264.06	118.67
	150	101.9	305.55	43.59	209.45	253.04	52.51
	200	87.5	262.50	38.01	209.45	247.46	15.04
	300	78.1	234.15	27.18	209.45	236.63	-2.48
Good surface drainage	33	141.6	424.73	131.66	209.45	341.11	83.62
	50	140.0	480.00	97.55	209.45	307.00	113.00
	60	139.3	417.90	86.53	209.45	295.98	121.92
	75	137.6	412.65	75.50	209.45	284.95	127.70
	100	131.3	393.75	64.45	209.45	273.90	119.85
	150	111.1	333.38	53.43	209.45	262.88	70.50
	200	100.1	300.30	47.91	209.45	257.36	42.94
	300	89.4	$268.28	$37.08	$209.45	$246.53	$21.75

* Net return is the return or profit to land and management based on a corn price of $3.00 per bushel.

Minimum management of the controlled drainage system is assumed. Intensive management could increase net return by up to 10 percent. See the text for further details.

Table 8. Predicted Net Return for Subsurface Drainage and Subirrigation on a Poorly Drained Soil Planted to Continuous Corn

	Tile spacing (feet)	Predicted yield (bu/acre)	Gross income per acre	System cost per acre	Production cost per cre	Total cost per acre	Net return per acre
Well Water Source							
Fair surface drainage	33	168.5	$505.58	$161.60	$224.73	$386.33	$119.25
	50	162.9	488.78	127.49	224.73	352.22	136.56
	60	158.6	475.65	116.47	224.73	341.20	134.45
	75	152.1	456.23	105.44	224.73	330.17	126.06
	100	138.3	414.75	94.39	224.73	319.12	95.63
	150	108.3	324.98	83.37	224.73	308.10	16.88
	200	90.5	271.43	77.83	224.73	302.58	-31.15
	300	79.5	238.35	66.24	224.73	290.97	-52.62
Good surface drainage	33	168.7	506.10	171.50	224.73	396.23	109.87
	50	163.3	489.83	137.39	224.73	362.12	127.71
	60	159.3	477.75	126.37	224.73	351.10	126.65
	75	154.5	463.58	115.34	224.73	340.07	123.51
	100	140.9	422.63	104.29	224.73	329.02	93.61
	150	118.3	354.90	93.27	224.73	318.00	36.90
	200	102.6	307.65	87.75	224.73	312.48	-4.83
	300	91.5	274.58	76.92	224.73	301.65	-27.07
Surface Water Source							
Fair surface drainage	33	168.5	505.58	133.80	224.73	358.58	147.02
	50	162.9	488.78	99.72	224.73	324.45	164.33
	60	158.6	475.65	88.70	224.73	313.43	162.22
	75	152.1	456.23	77.67	224.73	302.40	153.83
	100	138.3	414.75	66.62	224.73	291.35	123.40
	150	108.3	324.78	55.60	224.73	280.33	44.65
	200	90.5	271.43	50.08	224.73	274.81	-3.38
	300	79.5	$238.35	$39.25	$224.73	$263.98	$-25.63

*Net return is the return or profit to land and management based on a corn price of $3.00 per bushel.
Minimum management of the controlled drainage system is assumed. Intensive management could increase net return by up to 10 percent. See the text for further details.

Table 9. Predicted Net Return for Conventional Center-Pivot Irrigation and Subsurface Drainage on a Poorly Drained Soil Planted to Continuous Corn

	Tile spacing (feet)	Predicted yield (bu/acre)	Gross income per acre	System cost per acre	Production cost per acre	Total cost per acre	Net return per acre
Well Water Source							
Fair surface drainage	33	175.0	$525.00	$226.01	$224.73	$450.74	$74.26
	50	174.7	523.95	191.90	224.73	416.63	107.32
	60	173.8	521.33	180.88	224.73	405.61	115.72
	75	171.9	515.55	169.85	224.73	394.58	120.97
	100	163.8	491.40	158.80	224.73	383.53	107.87
	150	133.9	401.63	147.78	224.73	372.51	29.12
	200	116.4	349.13	142.26	224.73	366.99	-17.86
	300	102.2	306.60	131.43	224.73	356.16	-49.56
Surface Water Source							
Fair surface drainage	33	175.0	525.00	199.65	224.73	424.38	100.62
	50	174.7	523.95	175.54	224.73	400.27	123.68
	60	173.8	521.33	154.52	224.73	379.25	142.08
	75	171.9	515.55	143.49	224.73	368.22	147.33
	100	163.8	491.40	132.44	224.73	357.17	134.23
	150	133.9	401.63	121.42	224.73	346.15	55.48
	200	116.4	349.13	115.90	224.73	340.63	8.50
	300	102.2	$306.60	$105.07	$224.73	$329.80	$-23.20

*Net return is the return or profit to land and management based on a corn price of $3.00 per bushel.

Conventional Subsurface Drainage

Table 6 shows the influence of subsurface drain spacing and the quality of surface drainage on net annual profit with a conventional subsurface drainage system. The optimum tile spacing (that which results in maximum profit) is 75 feet for both good and fair surface drainage. The maximum profit, however, occurs with fair surface drainage even though yields are slightly higher when good surface drainage is provided.

This trend is fairly typical for North Carolina soils with good potential for subsurface drainage. When good subsurface drainage cannot be or is not provided (for example, with 300-foot spacing), providing good surface drainage becomes more important. For soils with good potential for subsurface drainage, however, it is usually more cost effective to provide the subsurface drainage than to improve surface drainage. On the other hand, if the subsoil is fairly "tight" (if it has poor potential for subsurface drainage), it is usually more cost effective to improve the surface drainage.

Controlled Subsurface Drainage

Table 7 shows the Influence of drain spacing and the quality of surface drainage for controlled subsurface drainage. Again, maximum profit occurs at a tile spacing of 75 feet for both fair and good surface drainage. As with the conventional drainage system, yields are slightly higher with better surface drainage, but the increased yield is not sufficient to offset the cost of improving the surface drainage. Also, maximum profit is slightly higher with conventional drainage than with controlled drainage, indicating that, based on average yields, the increased yield with controlled drainage would not pay for the cost of the control structure. This situation occurs because on this example site three structures would be required to maintain the desired water table level. If fewer structures could be used or if the cost of the structures were reduced, controlled drainage might be a more economical alternative for this site.

In general, soils with high drainable porosity show the greatest benefit from controlled drainage, whereas soils with low drainable porosity show a greater return from conventional drainage alone. Such is the case with this site. The soil properties used for the model were those of a soil with medium drainable porosity, and thus controlled drainage is not profitable for these specific conditions.

One of the basic assumptions used in predicting yields with DRAINMOD is that system management is kept at a minimum. For example, the model does not allow the level of the control structure to be changed during temporary wet periods. In a real situation, the farmer would likely lower the control structure to increase drainage rates at such times. Thus yields could be from 2 to 5 percent higher and net return could be increased by up to 10 percent if the drainage system were carefully monitored and controlled.

Irrigation

Predicted yields and profit are shown in Table 8 for subirrigation and in Table 9 for overhead (center-pivot) irrigation. It was assumed that improved drainage would be necessary to accommodate overhead irrigation, and thus drain spacings are shown for both systems. Maximum profit with a subirrigation system occurs at a tile spacing of 50 feet for both fair and good surface drainage. As in the two previous alternatives, the cost of improved surface drainage cannot be recovered on this site when good subsurface drainage is provided. As the quality of subsurface drainage decreases, however, surface drainage becomes more important.

When drainage is improved on this poorly drained site, excellent corn yields result. Thus a limited additional benefit can be realized from irrigation. Compared to conventional drainage, subirrigation is only marginally more profitable ($ 1.26 per acre per year) if a deep well is used as the water source. The cost of the water source is the primary factor affecting profits with irrigation. When a surface water supply is available, use of subirrigation will boost profits by $29.08 per acre over conventional drainage (Table 8).

Regardless of the type of water supply used, subirrigation is considerably more profitable on this site than the combination of conventional drainage with an overhead (center-pivot) irrigation system. In fact, when the costs of providing subsurface drainage, a water supply, and a center-pivot system are combined, the profit with overhead irrigation is considerably less than for all other options.

Intensive management-careful monitoring and control of the system-can affect yields and profits with a subirrigation system just as it can with a controlled drainage system, as discussed earlier. The benefit of intensive management increases as the system drainage capacity decreases (that is, as the tile spacing increases). At very close tile spacings, intensive management is not necessary. At spacings close to or greater than the optimum, however, yields can be increased 2 to 5 percent (and net return by up to 10 percent) with careful management.

One additional point should be considered when comparing yields and profits for the various alternatives. Production costs were adjusted to reflect average targeted yields as predicted by DRAINMOD. This adjustment resulted in increased nitrogen and harvesting costs with increased yield. Weather conditions that will produce the highest yields even without irrigation normally occur in about one of every five years. In the hope that the "good" year will be the year at hand, many growers manage their operation in anticipation of the higher yield. That is, their traditional management strategy is to use each year the seeding and fertilization rates that are sufficient to produce the highest yield (175 bushels per acre), even though average yields will be less in most years when water is the limiting factor.

Because production costs in this evaluation were adjusted for target yields, the production costs for conventional subsurface drainage are underestimated by about $10 per acre as compared to the irrigation alternatives if the farmer uses this traditional strategy. Under these circumstances, the irrigation alternatives are more attractive than the values shown by about $10 per acre as compared to conventional subsurface drainage.

Choose Your System Carefully

The maximum profit for each alternative is summarized in Figure 2. For the conditions assumed, subirrigation would be the most profitable choice. However, since the net profit with subirrigation is only slightly higher than that with conventional subsurface drainage, one must ask: Is the risk of the additional capital outlay justified by the increased profit? Only you can answer this question after carefully considering your own situation.

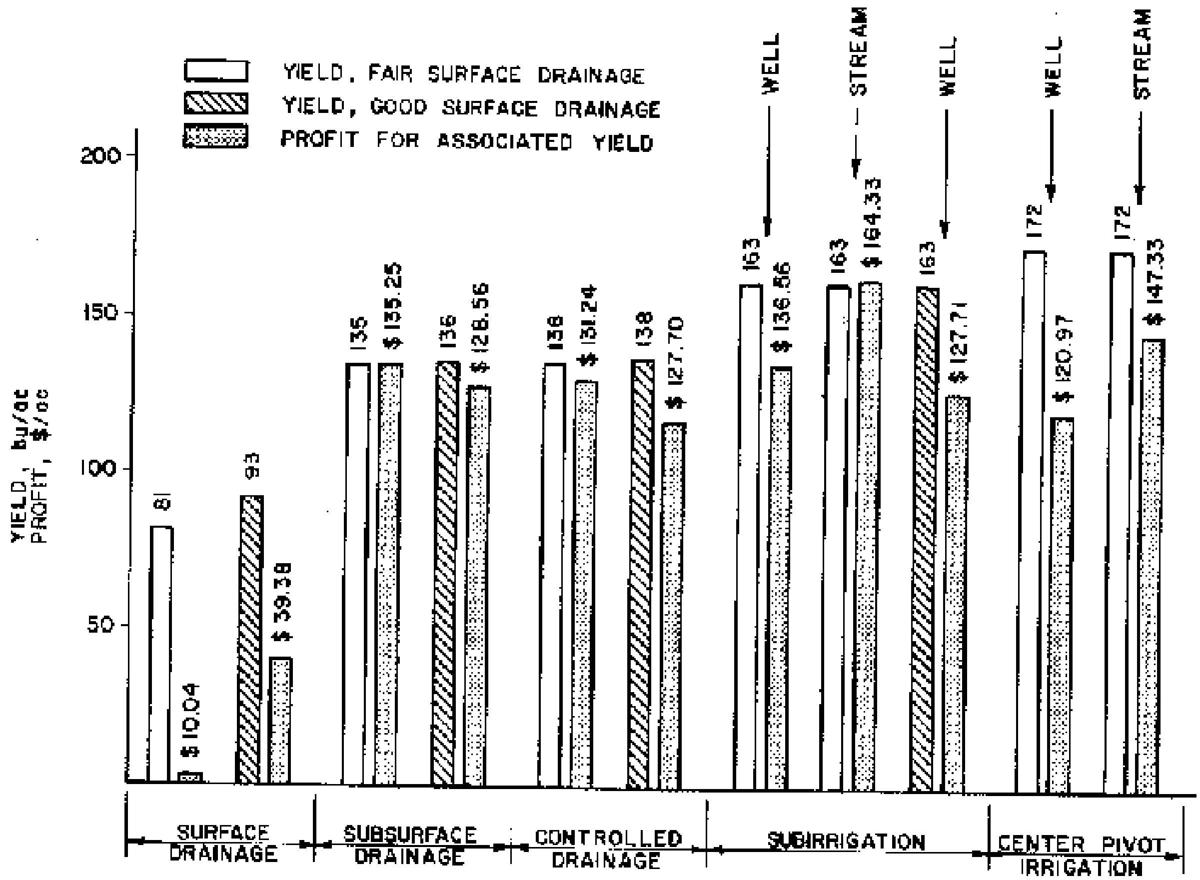

Figure 2. Influence of surface drainage, water source, and water management system on yield and profit for continuous corn.

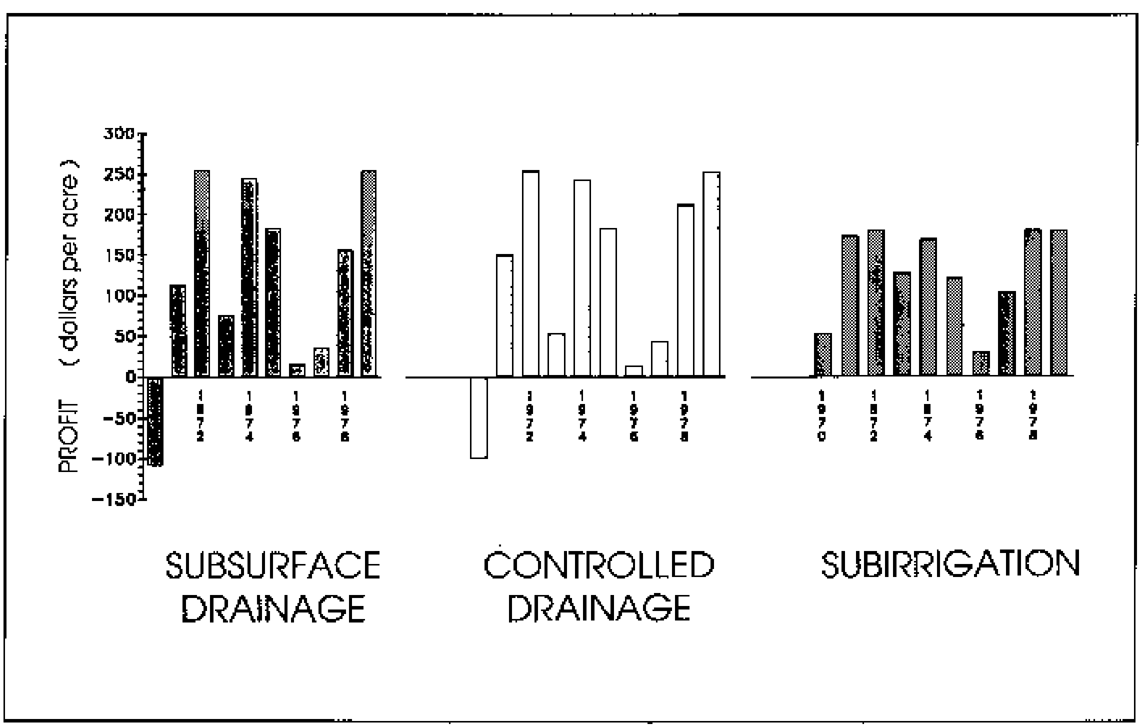

Figure 3. Fluctuations in annual net returns for conventional subsurface drainage, controlled subsurface drainage, and subirrigation

Thus far, we have considered only long-term average yields and projected profit. However, year-to-year variations in yield and profit could be of more importance than long-term averages. The year-to-year variation in profit over a 10-year period for each alternative is shown in Figure 3. In each case, the tile spacing used was that which provided the highest long-term average profit for each option. Notice that in some years (1972, for example) conventional subsurface drainage provided the most profit. Sometimes rain occurs at just the right time and in the right amount, so improved drainage or irrigation is not needed. Note also that conventional subsurface drainage showed the least profit (most loss) in other years (for example, in 1970).

Subirrigation, on the other hand, provided the most consistent year-to-year profit; a net profit was predicted every year. This benefit is very important, especially for growers who must meet annual financial obligations. Another way of viewing this situation is that subirrigation provided more control over one important factor that influences crop yield-that is, water. This control reduced the risk of not making a profit and helped to stabilize farm income. From this standpoint, subirrigation would be the most desirable option for this situation, whereas subsurface drainage alone may be adequate from the standpoint of long-term average profit.

When properly designed, subsurface drainage and subirrigation systems can often increase yield reliability and net farm income significantly. However, soil and site conditions vary from field to field, and the results reported here cannot be applied to every situation. North Carolina has more than 2 million acres of poorly drained cropland. Controlled drainage, subirrigation, or both would be very profitable on about 1 million of these acres. On the other hand, controlled drainage or subirrigation could be unprofitable on the other 1 million acres.

Because subsurface drainage and subirrigation systems are expensive, careful planning and design of these systems is crucial. Economic evaluation of all alternatives is a very important part of the planning and design process. Be sure to seek professional assistance when evaluating your water management needs. Your county Agricultural Extension Service agent and Soil Conservation Service personnel can help you evaluate the potential costs and benefits of water management alternatives for your farm.

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